# OPERATION OF HORSE POWER METER APPLIED TO A REAR WHEEL DYNAMOMETER FOR TESTING AUTOMOBILES

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THE DESIGN, CONSTRUCTION, AND OPERATION OF A HORSE POWER

METER AS APPLIED TO A REAR WHEEL DYNAMOMETER

FOR TESTING AUTOMOBILES.

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## * OBJECT *

The object of this thesis is the construction of a horse power meter to be used in conjunction with a rear wheel absorption dynamometer, for the measurement of the horse power delivered at the rear wheels of an automobile.

## * DEFINITION *

A horse-power meter is a mechanism, having:- speed registering auxilliaries, which move an indicator across a chart; and torque registering auxilliaries which cause a drum carrying the chart to rotate. The result of the two motions furnishes a means of determining the horse-power being delivered by the rear wheels at any speed of the driving wheels.

## * PREFACE *

This thesis is the third one to be presented on the subject of a horse power meter, which is to be used for measuring the power delivered at the rear wheel of an automobile.

The work of designing, and constructing a horse power meter was begun by senior members of the mechanical engineering department, class of 1914. They found the time at their disposal too limited for the completion of the work, and therefore concentrated their efforts towards the completion of a suitable rear wheel dynamometer, which was to be used in conjunction with the horse power meter.

The next group of men to cope with this problem were members of the class of 1915. They designed and constructed an oil reservoir which by means of a corrugated diaphragm transmits the torque developed in the rear wheel dynamometer to an oil manometer which controls the torque registering apparatus of the horse power meter.

The remainder of the time at their disposal was spent in unsuccessful designs of suitable transmission gearing for a tachometer which actuates the speed mechanism of the horse power meter.

The problem which must now be solved is the construction of a suitable transmission for connecting a flexible steel shaft from the tachometer mechanism of the horse-power meter to the split gear on the shaft of the dynamometer. After the proper transmission has been made, a proper chart will have to be drawn for the indicating mechanism of the horse-power meter.

## DESCRIPTION OF APPARATUS.

THE AUTOMOBILE. The automobile chassis which will be used in this work is a HALLADAY 1911 model. The engine is a four cylinder, four cycle, 4-1/2" bore, and 5" stroke RUTENBER model R-A, and is rated at 40 H.P. by the makers. The cylinders are cast singly, and are bolted to the crank case. The cooling water is circulated by a brass gear pump, and cooling of the jacket water is accomplished by means of a honeycomb radiator and a fan. The car is equipped with a multiple disk clutch run in oil, and a small surface brake. The gearing is of the selective type and is as follows:-

| | | | |
|---|---|---|---|
| 1. First | 11.45 | to 1 | |
| 2. Second | 5.83 | to 1 | |
| 3. Third | 3.50 | to 1 | (direct) |
| 4. Reverse | 13.33 | to 1 | |

The propeller shaft is enclosed in a tubular torque case, and has a universal joint. The rear axel is of the full-floating type. The wheels are made to carry 3-1/2" x 36" tires.

THE DYNAMOMETER. The dynamometer to be used in this test is an ALLEN water dynamometer. The dynamometer proper comprises; a cast iron disk firmly keyed to a 2" chrome nickle steel shaft; a copper friction disk placed on each side of the cast iron disk; and a cast iron casing, with stiffeners (ribs), on the outside, which casing encloses the two sets of disks, and holds the water which produces the pressure on the friction disks. A brake arm riveted to the casing transmits the torque developed in the dynamometer to the diaphragm of an oil reservoir. The water enters and leaves the casing thru 1/8" pipes, and serves the double purpose, of producing pressure on the friction disks, and carrying away the heat developed by the absorption of the power.

The shaft carrying the dynamometer is mounted in four large bearings, and on the shaft between each pair of bearings is bolted split pulley wheels 3' - 10" in diameter, and 9-1/2" across the face. The rear wheels of the automobile will be backed onto the pulleys for the test. The

general layout of the apparatus is shown in fig. 1.

THE OIL RESERVOIR. The oil reservoir, to which the torque developed in the dynamometer will be transmitted, consists of a flanged cast iron bowl 2-3/8" deep, 12" internal diameter, and 16" across the face of the flange. A corrugated copper disk is fastened down on the top of the bowl by means of a cast iron ring fitted with 12 5/8" bolts. Within the center of the bowl, there is a small pedestal for preventing the diaphragm from being subjected to too great a depression. A cast iron disk, having a spherical bottom, rests on the diaphragm and serves to distribute the pressure produced by the torque arm.

The dynamometer and oil pressure reservoir are mounted on a test rack placed in a pit which is just deep enough to permit the rim of the large pulley wheels to project about an inch above the floor line. This arrangement facilitates the handling of any car which is to be tested.

THE HORSE-POWER METER. The horse-power

DETAILS OF
WATER POWER DYNAMOMETER

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meter mechanisms are contained within an aluminum casing. The tachometer mechanism, (see fig. 2), has three sets of gears; #1, #2 and #3, and #4, which give the following gear ratios:-

1. Ratio of 1 to 2 & 3 is 2 to 1

2. Ratio of 2 & 3 to 4 is 2 to 5.

Each set of gears is mounted on a shaft which projects beyond the case, and which passes thru a sleeve on the outside of the casing. The sleeve is threaded for a connection on the flexible shaft casing which may be securely fastened to the sleeve by this means. In this way, each gear may be connected in, and that speed of rotation of the governor shaft which gives the maximum range of travel of the indicator needle, for a given speed of the engine, can thereby be obtained.

The thread, which carries the indicating needle, connects to the circumference of wheel C, and passes over two small pulley wheels, mounted at each end of the upper drum over which the

paper chart travels.

The upper drum is turned by a small pulley wheel fastened to one end of the drum shaft. The pulley is rotated by a weighted string which is attached to a brass float resting on the surface of a mercury manometer. The mercury level rises and falls as the pressure in the oil reservoir increases or decreases. The pressure in the oil reservoir is transmitted to the manometer of the horse-power meter thru an eighth inch pipe which is filled with oil, and connects the reservoir with the manometer.

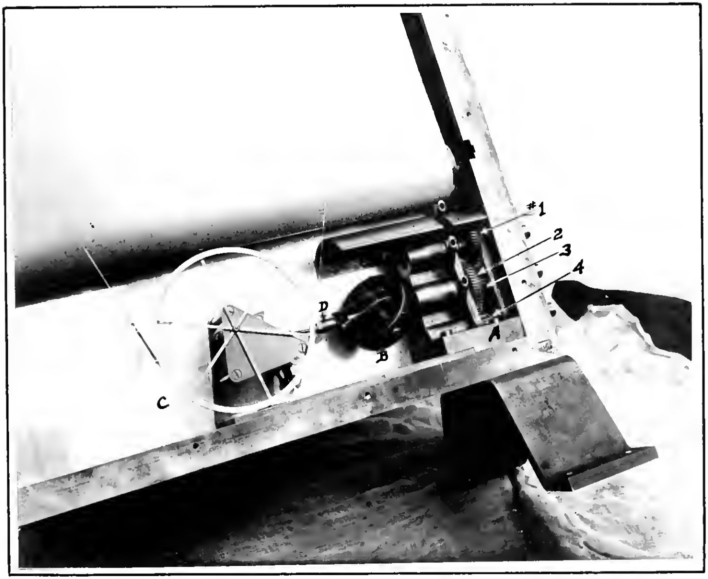


FIG. 2.

# CALIBRATION OF TORQUE, AND SPEED REGISTERING APPARATUS.

OIL PRESSURE RESERVOIR. The oil reservoir diaphragm which is to be used in the torque recording mechanism was calibrated in the following manner:-

The load was placed on the spherical plate, on the corrugated diaphragm, which supported a channel beam, on which we placed cast iron weights, weighing from 49 to 55 pounds each. In addition to the channel beam, we inserted a cast iron plate for balancing the load. The oil reservoir was connected by 1/8" copper piping to a 40 inch mercury manometer. A series of readings, ascending and descending were taken, and the average of those read which checked very closely were taken as the true calibration data. After the calibration was made, the weights which had been previously numbered were weighed on a FAIRBANKS platform scale.

The results of this calibration are given on the next page.

<u>Note</u>: Before calibrating the copper diaphragm, all the air was expelled by running oil thru the reservoir, and piping.

## DATA FOR OIL RESERVOIR CALIBRATION CURVE.

| Load applied on diaphragm in pounds:- | Difference in consecutive readings:- (In. Hg.) | Summation of consecutive readings:- (In. Hg.) |
|---|---|---|
| 0 | 0.00 | 0.00 |
| 26 | 1.85 | 1.85 |
| 86 | 4.85 | 6.70 |
| 135 | 3.91 | 10.61 |
| 187 | 3.11 | 13.72 |
| 237 | 2.94 | 16.66 |
| 287 | 2.78 | 19.44 |
| 342 | 3.03 | 22.47 |
| 392 | 2.65 | 25.12 |
| 441 | 2.41 | 27.53 |
| 492 | 2.47 | 30.00 |
| 542 | 2.31 | 32.31 |
| 592 | 2.24 | 34.55 |
| 642 | 1.98 | 36.53 |
| 693 | 1.77 | 38.30 |
| 748 | 1.52 | 39.82 |
| 798 | 1.59 | 41.41 |

HORSE-POWER METER TACHOMETER. The tachometer for the horse-power meter was calibrated in the machine shop in the following manner:-

The thick bottom of the gear housing A, (see fig. 2), was clamped in a vise, just firmly enough to prevent vibration; then, one end of a length of flexible shafting was coupled to the shaft supporting gear 1, and the other end was fastened in the jaws of a universal chuck, fastened to the spindle of a high speed lathe. A thread, partly wound on wheel C, had a key suspended at its free end which was placed along the edge of a steel scale clamped in a vertical position. As the speed of rotation increases, the plane of the governor weight tends to assume a position perpendicular to the axis of the shaft. At any constant speed, the position of the governor weight plane will make a constant angle with the axis, because the force of the centrifugal action will be balanced by the tension of the governor spring. The motion of the governor weight is transmitted

to the wheel to which the weighted thread is attached, and this causes the key to rise along the scale.

DATA FOR TACHOMETER CALIBRATION CURVE.

The travel of the key along the scale, at various speeds was as follows:-

| Revolutions Per Minute. (For gear 2 & 3) | Lift of Thread. (In inches) |
|---|---|
| 550 | 1.24 |
| 800 | 3.81 |
| 1100 | 6.24 |
| 1175 | 6.84 |
| 1500 | 8.79 |
| 2100 | 10.20 |
| 2200 | 10.22 |

## CONSTRUCTION OF TRANSMISSION GEARS.

The proper number of teeth for the gear which was to mesh with the split gear on the dynamometer shaft, and give the right amount of travel of the indicating pointer, was determined as follows:-

The maximum movement of the circumference of the tachometer wheel C. (See fig. 2), as determined in the calibration test, was 10.22 inches, at a speed of 2200 R.P.M. of the governor shaft D. The most regular portion of the curve lies between the ordinates representing 0 and 8 inches of lift. This would represent a travel of eight inches across the chart. The speed of rotation of gear 2 & 3 as shown on the chart, corresponding to a lift of 8 inches, is 1550 R.P.M.

The maximum speed of rotation of the engine on the HALLADAY car is about 1800 R.P.M. On direct drive the rear wheels would be rotating at a speed of 1800 + 3.5

or 514.29 R.P.M.

The speed of the pulley wheels on the dynamometer shaft is proportional to the product of the speed of the rear wheels and the inverse ratio of the square of the diameters; that is the speed of rotation of the dynamometer pulley wheels, when the rear wheels are making 514.29 R.P.M. is $(D_r^2 \div D_p^2) \times 514.29$ or 315 R.P.M.

The split gear on the dynamometer shaft has 62 teeth, 16 diametrical pitch, and the gear which will make the shaft carrying gears 2 & 3 rotate at 1350 R.P.M. when the split gear makes 315 R.P.M. will have $(320 \div 1350) \times 62 = 14.7$ or 15 teeth.

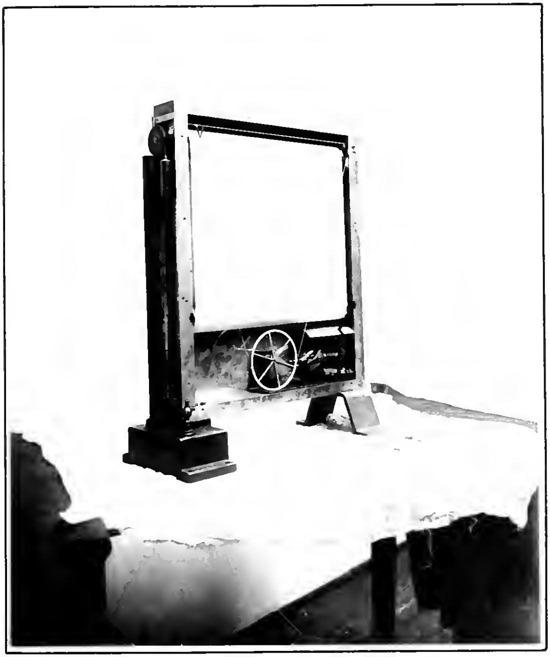

FIG. 5.

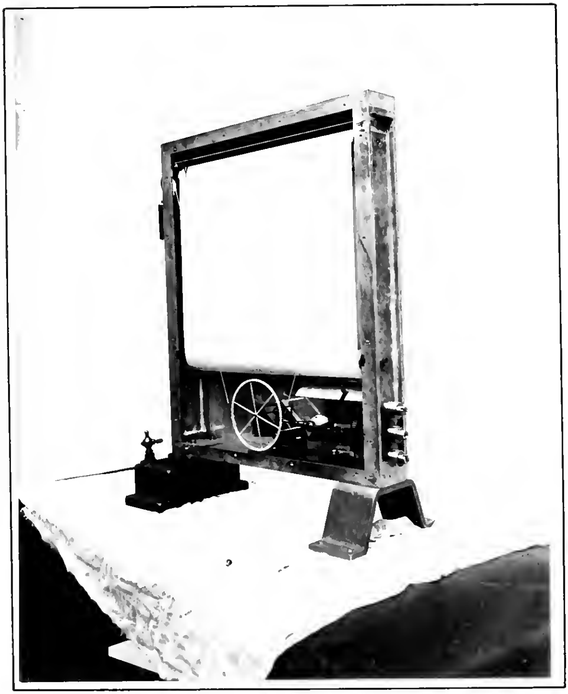

FIG. 6.

FIG. 7.

## PRELIMINARY WORK.

After we had bolted the H. P. meter to the top of table T, (see fig. 8), and coupled, to sleeve S, the flexible shaft leading from the pinion gear operated by the dynamometer shaft, we backed the car on to the pulley wheels W. Two pieces of cable attached to a spring scale, having a capacity of 1000 pounds, prevented the car from running off the pulley wheels, when the gears were put in mesh. The scale was put in to check the manometer mechanism of the H.P. meter while it is being calibrated.

As soon as everything had been connected up, we started the engine, and put the car on first gear, allowing it to idle slowly, so as to permit a careful watch to be kept on all parts of the apparatus. Everything appeared to be working as it should, and we then stopped the engine so as to permit a careful inspection to be made of all running parts. No faults were found during the inspection, so we atarted

the engine again. The engine started with a jerk, then almost stopped, and then ran with a jerky motion. We shut the engine down and made a very thorough search to find out what was wrong. We found that practically all the gear teeth of the idler gear, which works between the split gear and the pinion, had been stripped off. This was found to be due to the water pressure on the friction disks in the dynamometer. The water pressure prevented the engine from starting smoothly, and the jerking start stripped the cast iron teeth off the gear. Thereafter, the rear wheels were thrown into geat with the pressure removed from the dynamometer friction disks, and the engine would start up very smoothly. After the engine is driving the rear wheels, the water pressure can be applied in the dynamometer, without disturbing the smoothness of operation of apparatus.

We found it impossible to operate the

automobile for more than a half hour of continuous running, because of the excessive heating up of the engine. In fact the radiator would begin steaming like an open safety valve. We finally remedied this drawback by connecting a 1/8" copper tube from the cold water supply line to the radiator, and connecting the outlet of the overflow with a pipe leading to the sewer. In this way, the radiator was always kept full of hot water, but never so hot as to steam, and the engine could be operated continuously without overheating.

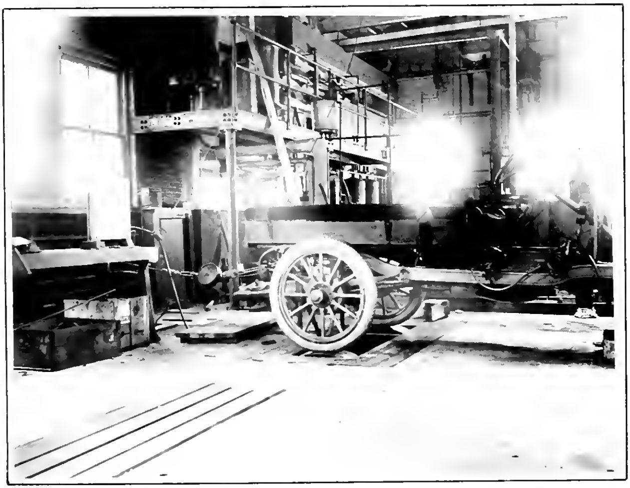

FIG. 8.

## CALIBRATION OF HORSE-POWER METER.

The tachometer, and manometer mechanisms, although once calibrated while separated from the case, gave data for determining, approximately, the proper length of mercury manometer for the H.P. meter, and the correct ratio of gear teeth for the pinion driving the flexible shaft. After the two mechanisms had been brought together, and properly connected to the remaining test apparatus, it was necessary to calibrate the two mechanisms, again, in order that a chart could be drawn for the meter.

MANOMETER CALIBRATION. The flexible shafting was disengaged from the driving pinion, and the engine put on direct drive. The water pressure in the dynamometer was regulated by means of the inlet valve, and a series of points were taken on the chart with the corresponding loads, as obtained from the spring scale, recorded. The distance, in inches, corresponding to the recorded pressure were summed up in table 1, and curve A, (see fig. 9) was plotted with this data.

TACHOMETER CALIBRATION. The flexible shafting was again connected up with the driving pinion, and the inlet, and outlet water valves were opened 2, and 1/2 turns respectively. The automobile was put on direct drive. The speed of rotation of shaft D, (see fig. 2) was taken with a hand tachometer, and points corresponding to the recorded speed were marked on the chart. The distance of horizontal travel of the pointer, and the corresponding R.P. . of shaft D, are given in table 2. The curve plotted with this data is shown in fig. 10. (curve B).

Table 3, contains data calculated results of H.P. delivered at the rear wheels, with the pressure on the diaphragm kept constant, and with variations of speed. This data was used to plot curves in fig. 10.

Table 4 contains results picked from the curves in fig. 9, and fig. 10; the D.H.P. and load on the copper diaphragm being taken from fig. 10, and the inches of vertical travel, corresponding to pressures on the diaphragm, being taken from fig. 9.

THE HORSE-POWER METER CHART. The horse-power meter chart was plotted with the data recorded in table 4.

TABLE I.

| Vertical travel of paper over drum in inches. | Brake load in pounds. |
|---|---|
| 0.0 | 0.0 |
| 1.7 | 38.0 |
| 3.5 | 65.0 |
| 5.13 | 111.0 |
| 5.77 | 126.5 |
| 6.64 | 160.0 |
| 7.05 | 180.0 |
| 7.50 | 188.0 |
| 8.23 | 229.0 |
| 9.22 | 278.0 |

TABLE 2.

| Horizontal travel of indicating pointing in inches | Governor shaft (D) R.P.M. | Rear wheel R.P.M. |
|---|---|---|
| 2.02 | 620 | 96 |
| 3.16 | 730 | 117 |
| 3.92 | 798 | 122 |
| 5.03 | 898 | 141 |
| 6.53 | 1112 | 176 |
| 7.51 | 1260 | 198 |
| 8.51 | 1460 | 230 |
| 9.64 | 2035 | 285 |

TABLE 3.

Length of brake arm equals radius of pulley wheel = 23"

$$D.H.P. = \frac{2\pi LWN}{33000} = \frac{2\pi \times 23 WN}{33000 \times 12} = 0.000365 WN$$

R. P. M. of dynamometer wheels = N = 28 x 15 x R.P.M. of (D)

N = 0.121 x R.P.M. of (D)

| R.P.M. (D) | Load on copper diaphragm in pounds. | | | | | |
|---|---|---|---|---|---|---|
| | 40 | 80 | 120 | 160 | 200 | 240 |
| | H.P. developed at rear wheels. | | | | | |
| 200 | 0.354 | 0.707 | 1.06 | 1.414 | 1.767 | 2.12 |
| 400 | 0.707 | 1.414 | 2.12 | 2.828 | 3.534 | 4.24 |
| 600 | 1.062 | 2.121 | 3.18 | 4.242 | 5.301 | 6.36 |
| 800 | 1.414 | 2.828 | 4.24 | 5.656 | 7.068 | 8.48 |
| 1000 | 1.767 | 3.535 | 5.30 | 7.07 | 8.835 | 10.60 |
| 1200 | 2.12 | 4.242 | 6.36 | 8.484 | 10.602 | 12.72 |
| 1400 | 2.478 | 4.949 | 7.42 | 9.898 | 12.369 | 14.84 |
| 1600 | 2.832 | 5.656 | 8.48 | 11.312 | 14.136 | 16.96 |
| 1800 | 3.186 | 6.363 | 9.54 | 12.726 | 15.903 | 19.08 |
| 2000 | 3.54 | 7.07 | 10.60 | 14.14 | 17.67 | 21.20 |

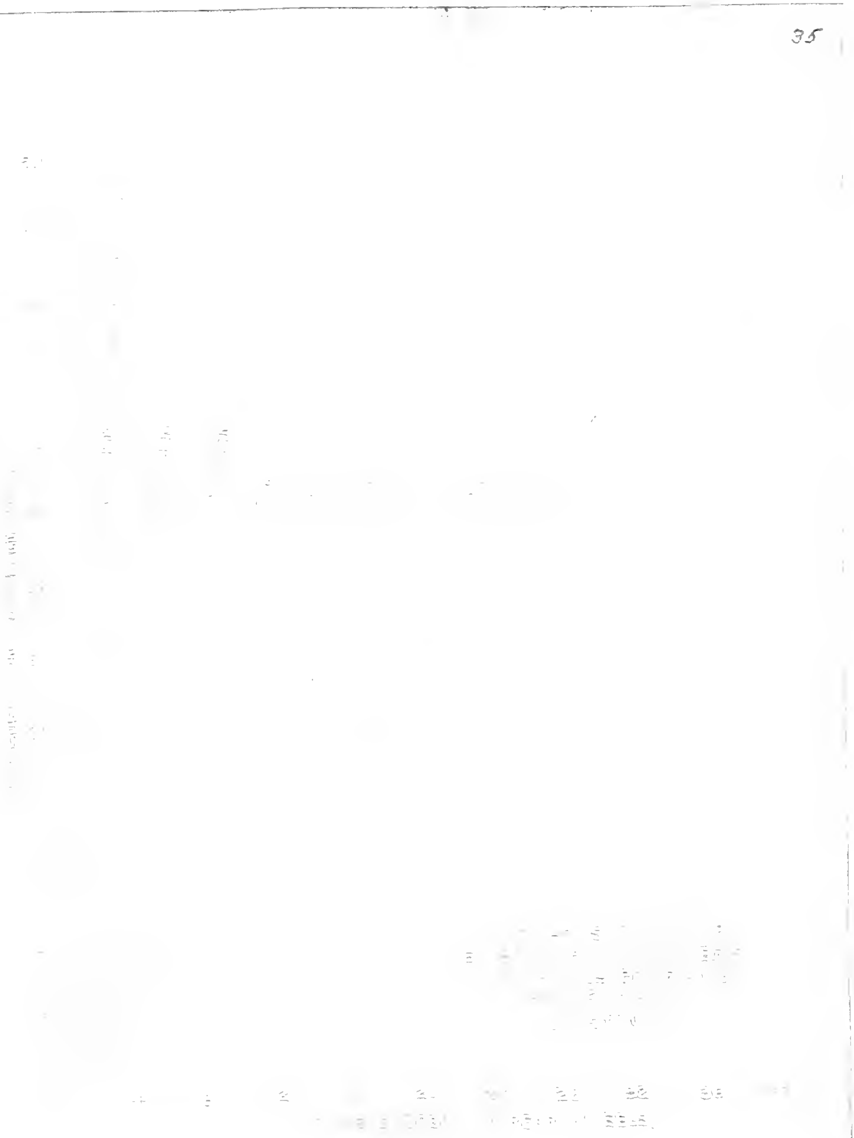

TABLE 4.

| R.P.M. of (D). | 200 | | 400 | | 600 | | 800 | | 1000 | |
|---|---|---|---|---|---|---|---|---|---|---|
| D.H.P. | Brake load. | Vertical travel in inches | Brake load | Vertical travel in inches | Brake load | Vertical travel in inches | Brake load | Vertical travel in inches | Brake load | Vertical travel in inches |
| 1.0 | 116 | 5.1 | 52 | 2.4 | 36 | 1.65 | 28 | 1.25 | 22 | 0.9 |
| 2.0 | 232 | 8.2 | 114 | 5.0 | 74 | 3.4 | 56 | 2.60 | 46 | 2.15 |
| 3.0 | 356 | 10.05 | 174 | 6.9 | 115 | 5.05 | 86 | 3.90 | 70 | 3.22 |
| 5.0 | | | 290 | 9.8 | 192 | 7.35 | 142 | 5.95 | 116 | 5.1 |
| 8.0 | | | 454 | | 302 | 9.92 | 225 | 8.06 | 182 | 7.1 |
| 10.0 | | | | | 378 | | 282 | 9.20 | 224 | 8.04 |
| 15.0 | | | | | | | 424 | | 345 | 9.96 |
| 20.0 | | | | | | | | | 456 | |
| 25.0 | | | | | | | | | | |
| 30.0 | | | | | | | | | | |
| 35.0 | | | | | | | | | | |

TABLE 4. (continued)

| R.P.M. of (D) | 1200 | | 1400 | | 1600 | | 1800 | | 2000 | |
|---|---|---|---|---|---|---|---|---|---|---|
| D.H.P. | Brake load. | Vertical travel in inches | Brake load | Vertical travel in inches | Brake load | Vertical travel in inches | Brake load | Vertical travel in inches | Brake load | Vertical travel in inches |
| 1.0 | 18 | 0.70 | | | | | | | | |
| 2.0 | 38 | 1.75 | 33 | 1.5 | 30 | 1.35 | 26 | 1.10 | 22 | 0.9 |
| 3.0 | 59 | 2.75 | 50 | 2.3 | 44 | 2.05 | 38 | 1.75 | 35 | 1.6 |
| 5.0 | 98 | 4.40 | 84 | 3.8 | 72 | 3.3 | 65 | 3.0 | 58 | 2.7 |
| 8.0 | 152 | 6.26 | 130 | 5.6 | 113 | 4.98 | 101 | 4.5 | 90 | 4.05 |
| 10.0 | 194 | 7.4 | 163 | 6.6 | 140 | 5.9 | 126 | 5.45 | 114 | 5.05 |
| 15.0 | 286 | 9.25 | 246 | 8.5 | 213 | 7.95 | 190 | 7.34 | 171 | 6.82 |
| 20.0 | 380 | | 327 | 9.8 | 282 | 9.20 | 252 | 8.65 | 227 | 8.1 |
| 25.0 | | | 408 | | 352 | 10.00 | 316 | 9.48 | 284 | 9.22 |
| 30.0 | | | | | 423 | | 378 | | 339 | 9.9 |
| 35.0 | | | | | | | | | 396 | |

## CONCLUSION.

The results which we have obtained with the H.P. meter have been very gratifying, and indicate that the H. P. meter can be developed into a commercial machine.

We would recommend the substitution of a telescoping shaft, with bevel gears, for the flexible shaft, as the speed of rotation, with a rigid connecting link, would be transmitted with greater smoothness and regularity. The flexible shafting, even at high speeds, is subject to jerking, and kinking, due to the friction between the casing, and the universal joints.

We would also recommend the substitution of a drum of smaller diameter for the lower drum of the H.P. meter, as this change would remove the element of friction of the thread from wheel C on the chart. This friction, although very small aids the tendency for the chart to slip on the drums.

Finally, we wish to state, that if a quantity of light machine oil be poured into the mercury manometer tube, such that the level of the oil remains

about a half inch below the top of the float, the float will rise, and fall with the mercury level without showing a tendency to-wards sticking.

REMARKS.

We are greatly indebted to Messers Koesch, and Huntley for the assistance and advice which they have given us from time to time during the progress of this work.